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(54) Title: AN IONIC LIQUID CATALYST HAVING A HIGH MOLAR RATIO OF ALUMINUM TO NITROGEN

(57) Abstract: An ionic liquid catalyst is provided comprising an ammonium chloroaluminate salt, and having a molar ratio of Al to N greater than 2.0 when held at a temperature at or below 25°C for at least two hours. There is also provided an ionic liquid catalyst comprising an alkyl-pyridinium haloaluminate and an impurity, wherein the ionic liquid catalyst has a molar ratio of Al to N greater than 2.0 when held at a temperature at or below 25°C for at least two hours. In a third embodiment, there is provided an ionic liquid system for isoparaffin/olefin alkylation, comprising a quaternary ammonium chloroaluminate, a conjunct polymer, and a hydrogen chloride. The ionic liquid system has a molar ratio of Al to N from 2.1 to 8.0. Less than 0.1 wt% AlCl₃ precipitates from the ionic liquid system when it is held for three hours or longer at or below 25°C.



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AN IONIC LIQUID CATALYST HAVING A HIGH MOLAR RATIO OF ALUMINUM TO NITROGEN

This application is related to co-filed patent applications titled "Process to
5 Make a Liquid Catalyst Having a High Molar Ratio of Aluminum to Nitrogen"
and "A Process for Hydrocarbon Conversion Using, A Method to Make, and
Compositions of, an Acid Catalyst," herein incorporated by reference in their
entireties.

FIELD OF THE INVENTION

This invention is directed to ionic liquid catalysts and an ionic liquid catalyst
system having a molar ratio of Al to N greater than 2.0.

DETAILED DESCRIPTION OF THE INVENTION

An ionic liquid catalyst comprising an ammonium chloroaluminate salt
is provided. The ionic liquid catalyst has a molar ratio of Al to N greater than
2.0, when the ionic liquid catalyst is held at a temperature at or below 25°C for
20 at least two hours.

There is also provided an ionic liquid catalyst comprising an alkyl-
pyridinium haloaluminate and an impurity, wherein the ionic liquid catalyst has
a molar ratio of Al to N greater than 2.0 when the ionic liquid catalyst is held at
a temperature at or below 25°C for at least two hours.

25 In a third embodiment, there is provided an ionic liquid system for
isoparaffin/olefin alkylation, comprising a quaternary ammonium
chloroaluminate, a conjunct polymer, and a hydrogen chloride. The ionic
liquid system has a molar ratio of Al to N from 2.1 to 8.0. Less than 0.1 wt%
AlCl₃ precipitates from the ionic liquid system when it is held for three hours or
30 longer at 25°C or lower.

Definitions:

The term "comprising" means including the elements or steps that are identified following that term, but any such elements or steps are not exhaustive, and an embodiment may include other elements or steps.

5 "Ionic liquids" are liquids whose make-up is comprised of ions as a combination of cations and anions. The most common ionic liquids are those prepared from organic-based cations and inorganic or organic anions. Ionic liquid catalysts are used in a wide variety of reactions, including Friedel-Crafts reactions.

10 "Alkyl" means a linear saturated hydrocarbon of one to nine carbon atoms or a branched saturated hydrocarbon of three to twelve carbon atoms. In one embodiment, the alkyl groups are methyl. Examples of alkyl groups include, but are not limited to, groups such as methyl, ethyl, n-propyl, isopropyl, n-butyl, isobutyl, sec-butyl, t-butyl, n-pentyl, and the like.

15

Ionic Liquid Catalyst:

The ionic liquid catalyst is composed of at least two components which form a complex. To be effective at alkylation the ionic liquid catalyst is acidic. The ionic liquid catalyst comprises a first component and a second
20 component. The first component of the catalyst will typically comprise a Lewis acid compound. Lewis acids that are useful for alkylations include, but are not limited to, aluminum halides, gallium halides, indium halides, iron halides, tin halides and titanium halides. In one embodiment the first component is aluminum halide or gallium halide. For example, aluminum trichloride (AlCl_3)
25 may be used as the first component for preparing the ionic liquid catalyst.

The second component making up the ionic liquid catalyst is an organic salt or mixture of salts. These salts may be characterized by the general formula Q^+A^- , wherein Q^+ is an ammonium, phosphonium, or sulfonium cation and A^- is a negatively charged ion such as Cl^- , Br^- , ClO_4^- , NO_3^- , BF_4^- ,
30 BCl_4^- , PF_6^- , SbF_6^- , AlCl_4^- , Al_2Cl_7^- , $\text{Al}_3\text{Cl}_{10}^-$, AlF_6^- , TaF_6^- , CuCl_2^- , FeCl_3^- , SO_3CF_3^- , , and 3-sulfurtrioxyphenyl. In one embodiment the second component is selected from those having quaternary ammonium halides containing one or more alkyl moieties having from about 1 to about 9 carbon atoms, such as, for example, trimethylammonium hydrochloride,

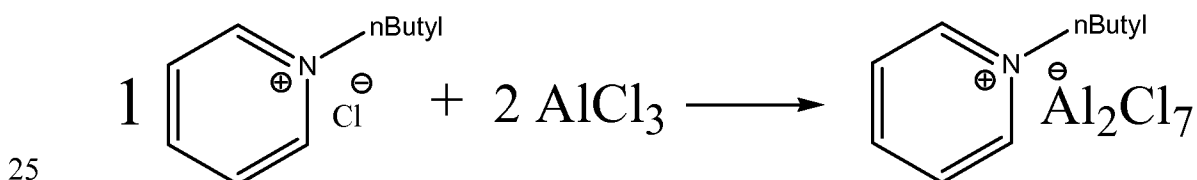
methyltributylammonium, 1-butylpyridinium, or alkyl substituted imidazolium halides, such as for example, 1-ethyl-3-methyl-imidazolium chloride.

In one embodiment the Al is in the form of AlCl_3 and the N is in the form of $\text{R}_4\text{N}^+\text{X}^-$ or $\text{R}_3\text{NH}^+\text{X}^-$, where R is an alkyl group and X is a halide. Examples of suitable halides are chloride, bromide, and iodide.

In one embodiment the ionic liquid catalyst is a quaternary ammonium chloroaluminate ionic liquid having the general formula $\text{RR}'\text{R}''\text{N}^+\text{H}^+\text{Al}_2\text{Cl}_7^-$, wherein RR' and R'' are alkyl groups containing 1 to 12 carbons. Examples of quaternary ammonium chloroaluminate ionic liquids are an N-alkyl-pyridinium chloroaluminate, an N-alkyl-alkylpyridinium chloroaluminate, a pyridinium hydrogen chloroaluminate, an alkyl pyridinium hydrogen chloroaluminate, a di-alkyl-imidazolium chloroaluminate, a tetra-alkyl-ammonium chloroaluminate, a tri-alkyl-ammonium hydrogen chloroaluminate, or a mixture thereof.

The presence of the first component should give the ionic liquid a Lewis or Franklin acidic character. Generally, the greater the mole ratio of the first component to the second component, the greater is the acidity of the ionic liquid mixture.

For example, a typical reaction mixture to prepare n-butyl pyridinium chloroaluminate ionic liquid salt having an Al/N molar ratio of 2.0 is shown below:



For the case of the above reaction, and for typical quaternary ammonium chloroaluminate salts, the molar ratio of Al to N cannot exceed 2.0 at room temperature for extended periods. This is because any additional AlCl_3 precipitates out and would not stay in the ionic liquid.

It has been discovered that the molar ratio of Al to N in the ionic liquid catalyst of this invention can be higher than what is possible in a freshly prepared quaternary ammonium chloroaluminate salt or alkyl pyridinium haloaluminate ionic liquid, which have a maximum molar ratio of Al to N of

2.0. In some embodiments the molar ratio of Al to N is greater than 2.1, greater than 2.5, or even greater than 2.8. In some embodiments the molar ratio of Al to N is less than 9, less than 8, less than 5, or less than 4. In one embodiment the molar ratio of Al to N is from 2.1 to 8; such as, for example, from 2.5 to 5.1 or from 2.5 to about 4.

In one aspect, the ionic liquid catalyst comprises an impurity in the catalyst that increases the catalyst's capacity to uptake more AlCl_3 in the catalyst phase. In one embodiment the catalyst comprises a conjunct polymer as an impurity which increases the catalyst's capacity to uptake AlCl_3 . In this embodiment the level of the conjunct polymer is present in an amount that still enables the ionic liquid catalyst or catalyst system to perform its desired catalytic function.

The presence of the impurity is an advantage over other ionic liquid catalysts comprising an impurity, because the impurity in this embodiment does not significantly inactivate the catalyst. The ionic liquid catalyst remains effective to perform its desired catalytic function. The ionic liquid catalyst can be used for a hydrocarbon conversion without having to stop the reaction and regenerate the catalyst for an extended period.

In one embodiment, an advantage of the ionic liquid catalyst having a molar ratio of Al to N greater than 2.0 is that it continues to function effectively to convert the hydrocarbon, without becoming significantly deactivated by conjunct polymer. In this embodiment the acid catalyst can be used continuously without having to be removed from the reactor for an extended period, or the catalyst drainage can be reduced. In this embodiment the acid catalyst may be regenerated in part, such that only a portion of the acid catalyst is regenerated at a time and the hydrocarbon conversion process does not need to be interrupted. For example, a slip stream of the ionic liquid catalyst effluent can be regenerated and recycled to a hydrocarbon conversion reactor. In one embodiment the level of the conjunct polymer is maintained within a desired range by partial regeneration in a continuous hydrocarbon conversion process.

The level of the impurity (e.g., conjunct polymer) will generally be less than or equal to 30 wt%, but examples of other desired ranges of impurity in the

ionic liquid catalyst or catalyst system are from 1 to 24 wt%, from 1 to 20 wt%, from 0.5 to 15 wt%, or from 0.5 to 12 wt%.

The term conjunct polymer was first used by Pines and Ipatieff to distinguish these polymeric molecules from typical polymers. Unlike typical polymers which are compounds formed from repeating units of smaller molecules by controlled or semi-controlled polymerizations, "conjunct polymers" are "pseudo-polymeric" compounds formed asymmetrically from two or more reacting units by concurrent acid-catalyzed transformations including polymerization, alkylation, cyclization, additions, eliminations and hydride transfer reactions. Consequently, the produced "pseudo-polymeric" may include a large number of compounds with varying structures and substitution patterns. The skeletal structures of "conjunct polymers", therefore, range from the very simple linear molecules to very complex multi-feature molecules.

Some examples of the likely polymeric species in conjunct polymers were reported by Miron et al. (Journal of Chemical and Engineering Data, 1963), and Pines (Chem. Tech, 1982). Conjunct polymers are also commonly known to those in the refining industry as "red oils" due to their reddish-amber color or "acid-soluble oils" due to their high uptake in the catalyst phase where paraffinic products and hydrocarbons with low olefinicity and low functional groups are usually immiscible in the catalyst phase. In this application, the term "conjunct polymers" also includes ASOs (acid-soluble-oils) and red oils.

The level of conjunct polymer in the acid catalyst is determined by hydrolysis of known weights of the catalyst. An example of a suitable test method is described in Example 3 of commonly assigned U.S. Patent Publication Number US20070142213A1. Conjunct polymers can be recovered from the acid catalyst by means of hydrolysis. The hydrolysis recovery methods employ procedures that lead to complete recovery of the conjunct polymers and are generally used for analytical and characterization purposes because it results in the destruction of the catalyst. Hydrolysis of the acid catalyst is done, for example, by stirring the spent catalyst in the presence of excess amount of water followed by extraction with low boiling hydrocarbon solvents such as pentane or hexane. In the hydrolysis process, the catalyst

salt and other salts formed during hydrolysis go into the aqueous layer while
conjunct polymers go into the organic solvent. The low boiling solvent
containing the conjunct polymers are concentrated on a rotary evaporator
under vacuum and moderate temperature to remove the extractant, leaving
5 behind the high boiling residual oils (conjunct polymers) which are collected
and analyzed. The low boiling extractants can be also removed by distillation
methods.

In one embodiment, the higher the level of conjunct polymer in the ionic
liquid catalyst or catalyst system the higher is the molar ratio of Al to N. This
10 is because the catalyst's capacity for uptake of AlCl_3 increases at higher
conjunct polymer concentration in the catalyst phase.

In one embodiment, the solubility of incremental AlCl_3 above the 2.0
Al/N molar ratio in the ionic liquid catalyst or catalyst system is 3 wt% or
higher at 50°C or below. In other embodiments the solubility of incremental
15 AlCl_3 above the 2.0 Al/N molar ratio in the ionic liquid catalyst or catalyst
system is from 3 wt% to 20 wt%, or from 4 wt% to 15 wt% at 50°C or below.

In one embodiment, the solubility of incremental AlCl_3 above the 2.0
Al/N molar ratio in the ionic liquid catalyst or catalyst system is significantly
higher at 100°C than at 50°C. For example the solubility of incremental AlCl_3
20 above the 2.0 Al/N molar ratio in the ionic liquid catalyst or catalyst system
can be greater than 10 wt% at 100°C, such as from 12 to 50 wt%, from 12 to
40 wt%, or from 15 to 35 wt% at 100°C. In one embodiment the solubility of
incremental AlCl_3 above the 2.0 Al/N molar ratio in the ionic liquid catalyst or
catalyst system is at least 10 wt% higher at 100°C than at 50°C.

In one embodiment, the AlCl_3 that is soluble and stable in the ionic
liquid catalyst or catalyst system remains soluble in the ionic liquid catalyst or
catalyst system. An example of this is where less than 0.1 wt%, less than
0.05 wt%, less than 0.01 wt%, or zero wt% AlCl_3 precipitates out of the ionic
liquid catalyst or catalyst system when it is held for at least three hours at
25 25°C or lower.

In one embodiment, the conjunct polymer is extractable. The conjunct
polymer may be extracted during a catalyst regeneration process, such as by
treatment of the catalyst with aluminum metal or with aluminum metal and
hydrogen chloride. Examples of methods for regenerating ionic liquid

catalysts are taught in U.S. Patent Publications US20070142215A1, US20070142213A1, US20070142676A1, US20070142214A1, US20070142216A1, US20070142211A1, US20070142217A1, US20070142218A1, US20070249485 A1, and in U.S. Patent Applications
5 11/960319, filed December 19, 2007; 12/003577, filed December 28, 2007; 12/003578, filed December 28, 2007; 12/099486, filed April 8, 2008; and 61/118215, filed November 26, 2008.

In some embodiments the ionic liquid catalyst is useful for catalyzing a hydrocarbon conversion reaction. One example of a hydrocarbon conversion
10 reaction is a Friedel-Crafts reaction. Other examples are alkylation, isomerization, hydrocracking, polymerization, dimerization, oligomerization, acylation, acetylation, metathesis, copolymerization, hydroformylation, dehalogenation, dehydration, olefin hydrogenation, and combinations thereof. For example, some of the ionic liquid catalysts are used for isoparaffin/olefin
15 alkylation. Examples of ionic liquid catalysts and their use for isoparaffin/olefin alkylation are taught, for example, in U.S. Patent Numbers 7,432,408 and 7,432,409, 7,285,698, and U.S. Patent Application Number 12/184069, filed July 31, 2008. High quality gasoline blending components and middle distillates can be made from these processes. In some
20 embodiments the alkylate from the isoparaffin/olefin alkylation has a Research-method octane number (RON) of 86 or higher, or even 92 or higher. The RON is determined using ASTM D 2699-07a. Additionally, the RON may be calculated [RON (GC)] from gas chromatography boiling range distribution data.

25 The time the catalyst is held at a temperature at or below 25°C can be fairly lengthy. In general, the time is for at least two hours, three hours or longer, up to two weeks, more than 50 days, several months, or even a year.

The alkyl-pyridinium haloaluminate may comprise a haloaluminate selected from the group consisting of chloroaluminate, fluoroaluminate,
30 bromoaluminate, iodoaluminate, and mixtures thereof. In one embodiment, the alkyl- is methyl, ethyl, propyl, butyl, pentyl, or hexyl.

In one embodiment, the hydrogen chloride is at least partially produced from an alkyl chloride. In one embodiment, the hydrogen chloride increases the acidity, and thus the activity of the ionic liquid catalyst. In one

embodiment, the hydrogen chloride, in combination with aluminum, assists in the conversion of the inactive anion AlCl_4^- to form the more acidic and effective chloroaluminate species for alkylation, such as AlCl_3 , Al_2Cl_7^- , or even $\text{Al}_3\text{Cl}_{10}^-$. In some embodiments, the alkyl chloride is derived from the

5 isoparaffin or olefin used in a given reaction. For example, with the alkylation of isobutene with butane in chloroaluminate ionic liquids, the alkyl chloride could be 1-butyl chloride, 2-butyl chloride, t-butyl chloride, or a mixture thereof. Other examples of alkyl chlorides that can be used are ethyl chloride, isopentyl chloride, hexyl chloride, or heptyl chloride. In one embodiment, the
10 amount of the alkyl chloride should be kept at low concentrations and not exceed the molar concentration of the Lewis acid portion of the catalyst, AlCl_3 . In one embodiment, the amounts of the alkyl chloride used may range from 0.05 mol % to 100 mol % of the Lewis acid portion of the ionic liquid catalyst, AlCl_3 . The amount of the alkyl chloride can be adjusted to keep the acidity of
15 the ionic liquid catalyst or ionic liquid catalyst system at the desired performing capacity. In another embodiment, the amount of the alkyl chloride is proportional to the olefin, and does not exceed the molar concentration of the olefin in the isoparaffin/olefin alkylation reaction.

Any term, abbreviation or shorthand not defined is understood to have
20 the ordinary meaning used by a person skilled in the art at the time the application is filed. The singular forms "a," "an," and "the," include plural references unless expressly and unequivocally limited to one instance.

All of the publications, patents and patent applications cited in this application are herein incorporated by reference in their entirety to the same
25 extent as if the disclosure of each individual publication, patent application or patent was specifically and individually indicated to be incorporated by reference in its entirety.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to
30 make and use the invention. Many modifications of the exemplary embodiments of the invention disclosed above will readily occur to those skilled in the art. Accordingly, the invention is to be construed as including all structure and methods that fall within the scope of the appended claims.

EXAMPLES

Example 1:

An isobutane-butene alkylation catalyzed with butyl pyridinium
5 chloroaluminate ionic liquid, and co-catalyzed with t-butyl chloride, was
performed in a continuous liquid phase reactor. During the alkylation, the
ionic liquid catalyst was continuously regenerated by mixing it with aluminum
metal at 100°C after each pass through the alkylation reactor. The aluminum
metal regeneration treatment reactivated the catalyst by removing most of the
10 conjunct polymers that accumulated as alkylation by-products in the catalyst
phase and by making and re-making AlCl_3 . The regeneration resulted in the
formation of excess AlCl_3 , depending on how much chloride sank into the
catalyst phase from the alkyl chloride used as a co-catalyst.

The level of conjunct polymer in the ionic liquid catalyst was maintained
15 between 2 and 23 wt% during the alkylation. Elemental analysis of the ionic
liquid showed that the molar ratio of Al to N increased over time during the
alkylation with no precipitation of excess AlCl_3 formed during the continuous
generation cycles. The freshly prepared ionic liquid, with no conjunct
polymer, had a molar ratio of Al to N of 2.0. During alkylation, the molar ratio
20 of Al to N in the liquid catalyst increased to 2.1, and then to 2.5 and then to
4.0 when sampled over a period of fifty plus days. Even with a higher molar
ratio of Al to N, the ionic liquid catalyst still remained effective for alkylation
and produced an alkylate product with a RON greater than 92. The higher
molar ratio of Al to N in the catalyst with conjunct polymer extended the life of
25 the ionic liquid catalyst before it required complete regeneration.

Example 2:

The solubility of incremental AlCl_3 above the 2.0 Al/N molar ratio in the
30 different samples of n-butyl pyridinium chloroaluminate ionic liquid catalyst
with different levels of conjunct-polymer impurity were tested at four different
temperatures. The solubility study results are summarized in Table 1, below.

Table 1

	Incremental AlCl_3 Solubility, Wt%			
	25°C	50°C	75°C	100°C
Fresh Catalyst with 0 wt% Conjunct Polymer	1.6	2	6.3	9.8
Regenerated Catalyst with ~2 wt% Conjunct Polymer	4	8	22	26
Regenerated Catalyst with 11 wt% Conjunct Polymer	8.4	9	22	29
Spent Catalyst with 15 wt% Conjunct Polymer	9	10	24	33

5 All of the samples of catalyst comprising conjunct polymer had a solubility of incremental AlCl_3 in the ionic liquid catalyst that was at least 10 wt% higher at 100°C than at 50°C. The samples, with various amounts of solubilized incremental AlCl_3 , were moved to room temperature and observed over time for AlCl_3 precipitation. Room temperature was approximately 25°C or below.

10 All of the incremental AlCl_3 that was initially soluble in the fresh catalyst precipitated out within two hours of standing at room temperature (e.g. at or below 25°C). Approximately 75% of the incremental AlCl_3 that was originally soluble in the regenerated catalyst with ~2 wt% conjunct polymer precipitated out within 72 hours of standing at room temperature.

15 A slight amount of incremental AlCl_3 precipitated out of the regenerated catalyst with 11 wt% conjunct polymer when it was held at room temperature overnight. No substantial additional amount precipitated out over a two week period of standing at room temperature.

20 No precipitation was observed in the spent catalyst samples held at room temperature for over two weeks.

WHAT IS CLAIMED IS:

1. An ionic liquid catalyst, comprising an ammonium chloroaluminate salt,
and having a molar ratio of Al to N greater than 2.0, when the ionic liquid
5 catalyst is held at a temperature at or below 25°C for at least two hours.
2. The ionic liquid catalyst of claim 1, wherein the Al is in the form of AlCl_3
and the N is in the form of $\text{R}_4\text{N}^+\text{X}^-$ or $\text{R}_3\text{NH}^+\text{X}^-$, where R is an alkyl group
and X is a halide.
3. The ionic liquid catalyst of claim 1, wherein the molar ratio of Al to N is
10 greater than 2.1.
4. The ionic liquid catalyst of claim 1, additionally comprising a conjunct
polymer, wherein the conjunct polymer is present in the catalyst at a level
from 1 to 24 wt%.
5. The ionic liquid catalyst of claim 1, wherein the solubility of incremental
15 AlCl_3 above the 2.0 Al/N molar ratio in the ionic liquid catalyst is 3 wt% or
higher at 50°C or below.
6. The ionic liquid catalyst of claim 1, wherein the solubility of incremental
 AlCl_3 above the 2.0 Al/N molar ratio in the ionic liquid catalyst is at least 10
wt% higher at 100°C than at 50°C.
- 20 7. The ionic liquid catalyst of claim 1, wherein less than 0.1 wt% AlCl_3
precipitates out of the ionic liquid catalyst when it is held for three hours or
longer at 25°C
8. The ionic liquid catalyst of claim 1, wherein the ionic liquid catalyst is used
for a hydrocarbon conversion reaction selected from the group of
25 alkylation, isomerization, hydrocracking, polymerization, dimerization,
oligomerization, acylation, acetylation, metathesis, copolymerization,
hydroformylation, dehalogenation, dehydration, olefin hydrogenation, and
combinations thereof.
9. The ionic liquid catalyst of claim 1, wherein the ammonium
30 chloroaluminate salt is an N-alkyl-pyridinium chloroaluminate, N-alkyl-
alkylpyridinium chloroaluminate, a pyridinium hydrogen chloroaluminate,
an alkyl pyridinium hydrogen chloroaluminate, a di-alkyl- imidazolium
chloroaluminate, a tetra-alkyl-ammonium chloroaluminate, a tri-alkyl-
ammonium hydrogen chloroaluminate, or a mixture thereof.

10. An ionic liquid catalyst, comprising an alkyl-pyridinium haloaluminate and an impurity, wherein the ionic liquid catalyst has a molar ratio of Al to N greater than 2.0 when the ionic liquid catalyst is held at a temperature at or below 25°C for at least two hours.
- 5 11. The ionic liquid catalyst of claim 10, wherein the alkyl-pyridinium haloaluminate comprises a haloaluminate selected from the group consisting of chloroaluminate, fluoroaluminate, bromoaluminate, iodoaluminate, and mixtures thereof.
- 10 12. The ionic liquid catalyst of claim 1 or claim 10, wherein the molar ratio of Al to N is from 2.1 to 8.0.
13. The ionic liquid catalyst of claim 10, wherein the solubility of incremental AlCl_3 above the 2.0 Al/N molar ratio in the ionic liquid catalyst is from 3 to 100 wt% at 100°C or below.
- 15 14. The ionic liquid catalyst of claim 10, wherein the impurity is present in the catalyst at a level from 1 to 24 wt%.
- 20 15. An ionic liquid system for an isoparaffin/olefin alkylation, comprising: a quaternary ammonium chloroaluminate, a conjunct polymer, and a hydrogen chloride; wherein the ionic liquid system has a molar ratio of Al to N from 2.1 to 8.0, and wherein less than 0.1 wt% AlCl_3 precipitates from the ionic liquid system when the ionic liquid system is held for three hours or longer at or below 25°C.
- 25 16. An alkylation reactor comprising the ionic liquid catalyst of claim 1 or claim 10.